Progress Report on Radiation Dosimetry at the VNIIM

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Introduction

This is a brief overview of radiation dosimetry activities at the D. I. Mendeleyev Institute for Metrology (VNIIM) during the period from May 2009 to April 2011 for the meeting of Section I (X- and gamma- rays, electrons) of the Consultative Committee on Ionizing Radiation (CCRI), May 4–6, 2011.

National primary standards development

The primary standard for X-rays and gamma radiation air kerma

<u>Gamma radiation</u>

The graphite-walled cylindrical cavity ionization chamber ND1005 purchased in 2008 has been recently adopted as the VNIIM primary standard for gamma radiation beams instead of C1 ionization chamber. It is manufactured by Georisk Kft., Hungary, in 2007 and has the certificate for dimensions, volume and electrical characteristics from the MKEH. The volume of the chamber is 1.020 cm^3, the graphite density is 1.73 g/cm^3. The correction factors for wall effects and for axial non-uniformity were calculated for this chamber using the CAVRZnrc code of the EGSnrc system developed by the NRC, Canada, and taking into account the calculated spectra of the VNIIM Co-60 and Cs-137 sources.

The ND1005 chamber characteristics were approved by the results of the comparison with the BIPM on air kerma for Co-60 and Cs-137 gamma radiation (BIPM.RI(I)-K1 and K5) held in November 2009.

<u>Medium energy X-rays</u>

The VNIIM primary standard for medium-energy X-rays is a free-air ionization chamber IK 70-300 of the conventional parallel-plate design. The measuring volume is defined by the diameter of the chamber aperture and the length of the collecting region.

IK 70-300 correction factors were re-evaluated for different radiation qualities. The correction factors with their uncertainties for the CCRI radiation qualities are presented in table 1. The correction factor for air attenuation k_a was determined using the measured air-attenuation coefficients. The uncertainty of the correction factor for field distortion k_d was estimated at the stage of chamber design. Other correction factors were calculated using the Monte Carlo code egs_fac described in Mainegra-Hing E., Raynaert N., Kawrakow I., Novel approach for the Monte Carlo calculation of free-air chamber correction factors, 2008, *Med. Phys.* **35** 3650–60.

Set of the correction factors for this chamber besides k_e, k_{sc} and k_{ap} includes two new correction factors, k_g and k_{CPE}, arising from the paradigm used by the authors of the Monte Carlo code egs_fac. The geometry correction factor k_g accounts, in principle, for any losses that arise from photons passing through the aperture with large angles, for example following scatter in the air path between the source and the aperture, and in practice is negligible. The correction for lack of charged-particle equilibrium k_{CPE} is also negligible and demonstrates that the attenuation length is sufficient to establish electron equilibrium. Transmission through the lead front plate of the chamber was measured to be negligible.

Table 1. Correction factors for the VNIIM
medium-energy X-rays primary standard ionization chamber

Radiation quality	100 kV	135 kV	180 kV	250 kV	$u_{i\text{A}}$	$u_{i\text{B}}$
Air attenuation k_a †	1.014 6	1.010 2	1.009 1	1.007 8	0.000 3	0.000 1
Photon scatter and fluorescence k_{sc}	0.990 9	0.992 0	0.993 3	0.994 3	-	0.001 0
Electron loss k_e	1.000 0	1.000 0	1.000 4	1.001 5	-	0.000 7
Ion recombination k_s	1.002 0	1.002 0	1.002 0	1.002 0	0.000 2	0.000 2
Field distortion k_d	1.000 0	1.000 0	1.000 0	1.000 0	-	0.000 5
Beam geometry k_g	1.000 0	1.000 0	1.000 0	1.000 0	-	0.000 2
Aperture k_{ap}	0.999 9	0.999 5	0.999 4	0.999 3	-	0.000 2
Charged-particle equilibrium k_{CPE}	1.000 0	1.000 0	1.000 0	1.000 0	-	0.000 1
Humidity k_h	0.998 0	0.998 0	0.998 0	0.998 0	-	0.000 3
$1 - g_{air}$	0.999 9	0.999 9	0.999 8	0.999 7	-	0.000 1

† Values for 293.15 K and 101.325 kPa.

New correction factors of the VNIIM primary standard chamber IK 70-300 were applied in the comparison with the BIPM for medium-energy X-rays air kerma (BIPM.RI(I)-K3) in October, 2010.

Low energy X-rays

The VNIIM primary standard for low-energy X-rays consists of three free-air parallel-plate ionization chambers: IK 10-60, IK 5-20 and IK 10-100. In 2011 IK 5-20 and IK 10-100 chambers were upgraded: to reduce heating of the chambers voltage dividers were replaced by new ones; volumes of the chambers were re-measured by the VNIIM Geometry measurements laboratory. IK 10-100 chamber was also fitted for temperature measurements inside it.

Re-equipment of the VNIIM low-energy X-ray primary standard installation started in 2007 is almost finished. New facilities, designed and purchased for the last 4 years include (Figure 1):

- two X-ray units with X-ray tubes: X-ray unit MG103/4.5 YXLON International with W-anode X-ray tube Y/TU/160-B02 and X-ray unit ISOVOLT 3003 with Mo-anode X-ray tube FA 100/3 type PW 2185/00;
- two beam formers with the automatic shutter closing and filters setting for the X-ray tubes;
- the calibration bench with ruler and laser alignment system;
- ORTEC HPGe planar detector GLP-06165/05 P4 for spectra measurement;
- electrical measurement and environmental monitoring system: two Keithley 6517A electrometers; Keithley 6517-RH humidity probe; F250-A-V thermometer with temperature probe T100-250-2D/T; BOP-1M-1 barometer.

New set of the radiation qualities, including the therapeutic radiation qualities, ISO4037 qualities for the radiation protection facilities calibration, IEC61267 qualities for the diagnostic apparatus control units calibration, was produced and investigated. Mammography radiation qualities were also established. HVL determination and spectra measurement were done for the CCRI radiation qualities.

The correction factors for IK 10-60, IK 5-20 and IK 10-100 primary standard chambers for the CCRI radiation qualities were calculated using the Monte Carlo code egs_fac.

The VNIIM low-energy X-ray air kerma comparison with the BIPM is planned for autumn 2011. The VNIIM also prepares for the mammography radiation air kerma key comparison.

In 2011 the VNIIM X-rays and gamma radiation air kerma primary standard is planned to undergo the procedure which is called "the Restatement of the Standard" and is aimed at bringing to correspondence all of the standard documentation with its latest modifications.

Figure 1. The VNIIM low-energy and mammography X-rays air kerma primary standard facilities

The primary standard for beta-radiation absorbed dose in tissue

In 2010 beta radiation source Tl-204 of the primary standard for beta-radiation absorbed dose in tissue was replaced by Kr-85 with activity 14.5 GBq (by Eckert&Ziegler Nuclitec GmbH, Germany).

The primary standard for flux, flux density and fluence of electrons, flux energy, flux density energy and energy fluence of electrons and bremsstrahlung radiation for energy up to 50 MeV

In 2009–2010 the primary standard for flux, flux density and fluence of electrons, flux energy, flux density energy and energy fluence of electrons and bremsstrahlung radiation for energy up to 50 MeV was used for the following investigations:

Characteristics of the standard charge and calorimetric detectors (Faraday cylinder and calorimeter-Faraday cylinder) were determined in scanned electron beams with flux density of electrons 2.8×10^{13}–6.5×10^{13} $s^{-1}cm^{-2}$, flux density energy 3.1–7.2 W/cm^2 and absorbed energy rate in graphite (absorbed dose rate in graphite) less than 3.7–8.5 W/g (200 kGy/min).

Characteristics of the calorimetric detector KS-1S used as a monitor were examined in the field of accelerator-sterilizer with maximum energy of 7.8 MeV, flux energy 900 W, flux density energy 12.0 W/cm^2, flux of electrons 1.95×10^{15} s^{-1}, flux density of electrons 3.7×10^{13} $s^{-1}cm^{-2}$, absorbed dose rate in graphite 5.0–20 kGy.

International activities

The comparison of the standards for air kerma of the VNIIM and the BIPM in Co-60 and Cs-137 radiation beams (BIPM.RI(I)-K1 and K5) was carried out in November 2009. In this comparison ionization chamber ND1005 was demonstrated as a primary standard of the VNIIM for the first time. The comparison was undertaken using a transfer standard – ionization chamber of thimble-type PTW-M30001.

The comparison result for Co-60 air kerma, based on the calibration coefficient for a transfer standard and expressed as a ratio of the VNIIM and the BIPM standards for air kerma, is 1.0008 with combined standard uncertainty of 1.8×10^{-3} [1].The comparison result for Cs-137 air kerma is expressed in the same way as for Co-60 is 1.0013 with combined standard uncertainty of 2.7×10^{-3} [2]. The results are in agreement within the combined standard uncertainties with those received in the previous comparison with the BIPM (1997), taking into account recalculation of the VNIIM primary standard chambers C1 and C30 correction factors and changes in the BIPM standard. The VNIIM-BIPM result for Co-60 air kerma comparison also matches within the combined standard uncertainties with the result obtained by the VNIIM in the EUROMET.RI(I)-K1 comparison in 2008.

The comparison between the air-kerma standards of the VNIIM and the BIPM in the X-ray range from 100 kV to 250 kV took place in October 2010. A thimble-type cavity ionization chamber PTW-TM30010 was used as transfer instrument. Re-evaluated set of the correction factors was used for the VNIIM primary standard chamber IK 70-300. The results of the comparison are presented in table 2, the stated standard uncertainty for the comparison is 1.8×10^{-3} [3]. The results are in moderately good agreement with those of the 1998 comparison between the standards of the VNIIM and the BIPM.

Table 2. The comparison results of the VNIIM and the BIPM primary standards for air-kerma in the X-ray range from 100 kV to 250 kV

Radiation quality	100 kV	135 kV	180 kV	250 kV
$R_{K,\mathrm{VNIIM}}$	1.001 4	1.001 8	1.002 6	1.002 6

In 2009–2010 the comparison of absorbed dose rate in tissue at radiation protection levels for beta dosimetry was performed between the VNIIM and the PTB. The radiation sources of both institutes (Sr-90/Y-90, Kr-85 and Pm-147) were calibrated using the primary standard measuring devices (extrapolation chambers) of both institutes, no transfer instrument was used. The comparison was performed in two steps. In the first step in 2009 the radiation fields of three radiation sources from the PTB (Pm-147, Kr-85 and Sr-90/Y-90 from the Beta Secondary Standards BSS 2) were measured at the VNIIM and in the second step in 2010 two radiation sources from the VNIIM (Pm-147 and Sr-90/Y-90 from the Beta Secondary Standard VET 9-1-86) were measured at the PTB. Consequently, no uncertainty contribution due to the usage of the transfer instrument comes into play.

The values of the absorbed dose rates in tissue agree within 1.2×10^{-2} for two different Sr-90/Y-90 sources, within 1.0×10^{-2} for one Kr-85 source and within 1.5×10^{-2} and 4.2×10^{-2} for two different Pm-147 sources respectively. All these deviations are within the assigned uncertainties [4].

Measuring instruments calibration and verification

In 2009–2011 the VNIIM performed the secondary and working standards calibration, verification and comparisons at the accredited dosimetry calibration laboratories, atomic power stations, clinics and for the manufacturers of the dosimetry instruments and sources, including TEST-St.-Petersburg (Saint-Petersburg), SNIIP (Moscow), FGUP RFYATS VNIIF (Sarov).

The secondary standards calibration was done for Belarussian State Institute of Metrology (BelGIM) (the Republic of Belarus).

More than 80 calibrations and verifications of working standards, including dosimetry souses (Cs-137, Co-60, Ra-226, Am-241, Cd-109, Ni-63, H-3, Sr-90/Y-90, Tl-204, Pm-147, Kr-85) were done. More than 1300 calibrations and verifications of measuring instruments for X-ray, gamma- and beta-radiation were performed, particularly TLD-systems Harshaw 6600 and KID-08C. Verification of the automated radiation monitoring system ASKRO AKRB-2000 was also performed for Leningrad atomic power station (the Leningrad region).

In October 2010 according to the decision of the 12th Technical Committee Meeting of the COOMET Quality Forum the VNIIM (and its dosimetry laboratory) received the confirmation of recognition of the Quality Management System in accordance with the Standard ISO/IEC 17025 and ISO Guide 34.

Measuring instruments testing for type approval and product certification for radiation safety

As the state testing center of Russia the VNIIM is responsible for the type approval checkout of the imported and home-produced devices to be used in dosimetry and certification (including functional testing and radiation protection control) of devices concerned with radiation but which are not a measuring instrument to authorize them for application.

For the last two years 15 Russian and foreign measuring instruments were tested for type approval: DAP (dose area product)-meters DIAMENTOR K1-S, K2-S (by PTW-Freiburg, Germany) and Kerma-X-Plus-DDP (by IBA Dosimetry, Germany); dosimeters SUPERMax (by Standard Imaging Inc., the USA), DMG-01 (by TAIFUN, Russia) and DKS-AT 5350 (by ATOMTEX, the Republic of Belarus); personal electronic dosimeters DOSICARD (by Canberra Industries Inc., the USA), EPD Mk2 (by Thermo Fisher Scientific Inc., the USA) and DTU-01 M (by NPP LT, Russia); TLD-systems Harshaw 6600 PLUS and Harshaw 6600 LITE (by Thermo Fisher Scientific Inc., the USA); BDMG-300 detectors (by INTRA, Russia); calibration sets UDG-AT 130 and UDG-AT 110 (by ATOMTEX, the Republic of Belarus).

Certification was performed for the customs control X-ray system with the X-ray TV-unit Colibri 150 TV (by FLASH ELECTRONICS, Russia) and for the digital radiography systems Fosfomatic (by TESTRON, Russia).

Regulations development

For the last two years procedures of measurement, calibration and verification were developed for different types of dosimetry measuring instruments, including DAP-meters, personal X-ray, gamma and beta radiation dosimeters. The procedure of personal dosimetry monitoring in the fields of photon, beta and neutron radiation was accomplished for TLD-system Harshaw 6600.

The VNIIM took part in the formulation of Sanitary Regulations and Standards "Hygienic requirements for location and operation of electron accelerators with energy less than 100 MeV" [5].

Publications and talks

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